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## **3 MIX DESIGN & PROPORTIONING**

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# CHAPTER THREE:

## MIX DESIGN

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### MIX DESIGN

The concrete mix design (CMD) for QC/QA superstructure concrete must produce a workable concrete mixture having properties that will not exceed the maximum and/or minimum values defined in the special provision. Workability in concrete defines its capacity to be placed, consolidated, and finished without harmful segregation or bleeding. Workability is affected by aggregate gradation, particle shape, proportioning of aggregate, amount and qualities of cementitious materials, presence of entrained air, amount and quality of high range water reducer, and consistency of mixture.

Consistency of the concrete mixture is its relative mobility and is measured in terms of slump. The higher the slump the more mobile the concrete, affecting the ease with which the concrete will flow during placement. Consistency is not synonymous with workability. Two different mix designs may have the same slump; however, their workability may be different.

Selection of target parameters by the contractor for any mix design must consider the influence of the following:

1. material availability and economics
2. variability of each material throughout period of usage
3. control capability of production plant
4. ambient conditions expected at the time(s) of concrete placement
5. logistics of concrete production, delivery, and placement
6. variability in testing concrete properties
7. generation of heat in large structural elements and differential in thermal gradient (i.e. 0.6 - 1 m thick and cement content above 355 kg/m<sup>3</sup>)

The qualities of the cementitious paste provide a primary influence on the properties of concrete. Proper selection of the cementitious content and water/cementitious ratio is dependent on the experience of the concrete producer and becomes a very important first step in preparing a design. For workable concrete, a higher water cementitious ratio is typically required when aggregate becomes more angular and rough textured. The presence of air, certain pozzolans, and aggregate proportioning will work to lower the water cementitious ratio; however the most significant reduction in water demand comes through the use of a high range water reducing chemical admixture.

Water/cementitious ratio is determined from the net, per unit, quantity of water and total cementitious materials (by weight). The net water content excludes water that is absorbed by the aggregates. For a given set of materials and conditions, as water/cementitious ratio increases, strength and unit weight will decrease. Compressive strength is a concrete parameter used in combination with unit weight and air content to evaluate the durability of the superstructure concrete's exposure to freeze / thaw action, and exposure to deicing salts. It is important to note that the designer of the bridge structure does not recognize the benefit of increased 28-day compressive strength. The slab still relies on a typical  $f'_c$  of 28 MPa.

Proportioning of aggregates is defined by the volume of fine aggregate to the volume of coarse aggregate, as a percent. The lower percentage of fine to total aggregate provides an increase in compressive strength at the expense of workability. The gradation, particle shape and texture of the coarse aggregate along with fineness modulus of the fine aggregate will determine how low the fine to total aggregate percentage can be for a given workability requirement.

## **MIXING PROPORTIONING**

Once the cement content, pozzolan content, water/cementitious ratio, and fine to total aggregate percentage are defined for the concrete's intended use in the superstructure, proportioning of the mix in terms of design batch weights can begin. Specific gravities must be accurately defined for each material being utilized in order to proportion the mix properly by the absolute volume method. Cement is typically accepted as having a specific gravity of 3.15. Pozzolans will typically vary between 2.22 and 2.77 depending on the type of pozzolan (fly ash, GGBFS, silica fume) and its source. Pozzolan suppliers should readily be able to provide current values for their material. Approximate specific gravities are identified for each source on the Department's Approved/Prequalified Materials list; however, they should not be considered the most current.

Bulk specific gravity, in the saturated surface dry condition, must be used to proportion the fine and coarse aggregate. Accurate testing of one or more samples of fine and coarse aggregate must be accomplished by the

Contractor as part of any proportioning for a mix design. It is of great benefit to identify the geologic ledges from which a crushed stone coarse aggregate is produced. Subsequent shifts in benching at the aggregate source may cause significant shifts in bulk specific gravity and absorption. These are important aggregate properties to monitor as part of concrete quality control.

Proportioning concrete by the absolute volume method involves calculating the volume of each ingredient and its contribution to making a single unit ( $\text{m}^3$ ) of concrete. Volumes are subsequently converted to design weights, which then become the basis for actual production of concrete from the plant. For cementitious materials and water, the weight to volume conversion is accomplished by dividing the weight (kg) by the specific gravity of the material and again dividing by the density of water ( $1000 \text{ kg/m}^3$ ). Converting from volume to weight is accomplished simply by taking the known volume ( $\text{m}^3$ ) of the ingredient and multiplying by the specific gravity of the ingredient and again multiplying by the density of water ( $1000 \text{ kgm}^3$ ). Volume to weight conversions for aggregates are accomplished by the same series of computations; however, bulk specific gravity (SSD) must be used. The target air content is established at 6.5% by the special provision, which easily converts to a volume of  $0.0650 \text{ m}^3$ .

### **Instructions for Page 1 of Mix Design & Proportioning Worksheets**

A worksheet entitled "Mix Design & Proportioning QC/QA Superstructure Concrete" has been developed and is included in Appendix D (Section 11) of this manual. Use of this form by the contractor and Department will provide an easy means to proportion a mix by the absolute volume method and validate compliance, thereby helping to eliminate delays due to errors and/or oversight of the specification requirements.

An example of proportioning a mix design through use of this form is detailed in Table 3.1. The contractor establishes the initial parameters for a mix design and serves as the starting point for subsequent proportioning calculations.

The initial step in proportioning the mix design is to calculate the water content per cubic meter. This is accomplished by multiplying the total cementitious content by the water/cementitious ratio. It should be noted that space was intentionally provided on the form to allow room for computations.

Example:  $400.0 \times 0.402 = 160.8 \text{ kg/m}^3$  water content

There is now sufficient information to begin entering known weights, volumes, and specific gravities into the second table. Table 3.2 illustrates the results for the example problem.

<b>Initial Parameters</b>	
Target Cement Content, kg/m <sup>3</sup>	<b>400.0</b>
Target Pozzolan Content, kg/m <sup>3</sup>	<b>0.0</b>
Target Silica Fume Content, kg/m <sup>3</sup>	<b>0.0</b>
Target Water / Cementitious Ratio, by wt.	<b>0.402</b>
Target Cement / Pozzolan Ratio, by wt.	<b>Infinity</b>
Target % Silica Fume	<b>0.0</b>
100 FA / FA+CA, Target, % by volume	<b>41.7</b>
FA Absorption, %	<b>1.1</b>
FA Bulk Sp. Gr. (SSD)	<b>2.694</b>
CA Absorption, %	<b>1.2</b>
CA Bulk Sp. Gr. (SSD)	<b>2.739</b>

Table 3.1

Material	Size, Type or Class	Source	Design Batch Weights kg/m <sup>3</sup>	Specific Gravity	Absolute Volume m <sup>3</sup>
Cement	Type I		<b>400.0</b>	3.150	<b>0.1270</b>
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS			<b>2.694</b>	
CA	#8 CS			<b>2.739</b>	
Water	potable		<b>160.8</b>	1.000	<b>0.1608</b>
Air	entrained	see table below	<b>0.0</b>	-NA-	<b>0.0650</b>
<b>Σ</b>	-NA-	-NA-		-NA-	1.0000

Table 3.2

The volume of total aggregates is now calculated by subtracting the volumes of other known ingredients (i.e. cement, pozzolan, silica fume, water, and air) from 1.0000 cubic meter of concrete.

Example:  $1.0000 - (0.1270 + 0.1608 + 0.0650) = 0.6472 \text{ m}^3$  total aggregates

The percentage of fine to total aggregate is divided by 100 to produce the decimal equivalent, and then multiplied by the total aggregate volume to determine the volume of fine aggregate only.

Example:  $0.6472 \text{ m}^3 \times 0.417 = 0.2699 \text{ m}^3$  fine aggregate

The corresponding volume of coarse aggregate is determined by subtracting the known volume of fine aggregate from the known volume of total aggregate.

Example:  $0.6472 \text{ m}^3 - 0.2699 \text{ m}^3 = 0.3773 \text{ m}^3$  coarse aggregate

These calculated values are now inserted in the appropriate cells of the table as shown in Table 3.3 by the values in boldface print.

Material	Size, Type or Class	Source	Design Batch Weights $\text{kg/m}^3$	Specific Gravity	Absolute Volume $\text{m}^3$
Cement	Type I		400.0	3.150	0.1270
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS			2.694	<b>0.2699</b>
CA	#8 CS			2.739	<b>0.3773</b>
Water	potable		160.8	1.000	0.1608
Air	entrained	see table below	0.0	-NA-	0.0650
$\Sigma$	-NA-	-NA-		-NA-	1.0000

Table 3.3

The volumes of fine and coarse aggregate are each converted to the design batch weight ( $\text{kg/m}^3$ ) based on saturated surface dry condition. The design batch weights are added to obtain the total weight of ingredients required to make  $1.000 \text{ m}^3$  of concrete at 6.5% target air content. Table 3.4 illustrates tabulation of the example problem.

Material	Size, Type or Class	Source	Design Batch Weights $\text{kg/m}^3$	Specific Gravity	Absolute Volume $\text{m}^3$
Cement	Type I		400.0	3.150	0.1270
Pozzolan	-----	-----	-----	-----	-----
Silica Fume	-----	-----	-----	-----	-----
FA	#23 NS		<b>727.1</b>	2.694	0.2699
CA	#8 CS		<b>1033.4</b>	2.739	0.3773
Water	potable		160.8	1.000	0.1608
Air	entrained	see table below	0.0	-NA-	0.0650
$\Sigma$	-NA-	-NA-	<b>2321.3</b>	-NA-	1.0000

Table 3.4

It should be noted that the volumes and weights of any water present in the admixtures are typically not included in the mix proportioning or in the water content determinations.

## LINEAR EQUATION OF UNIT WEIGHT vs. AIR CONTENT

It is known that the unit weight of plastic concrete is inversely proportional to air content. That is to say, as air content increases unit

weight decreases. This relationship becomes a very useful tool when evaluating plastic concrete. Unit weight and air content are properties of plastic concrete that can be easily and quickly measured in the field. A unit weight measurement, at a known air content, that deviates excessively from the linear relationship provides information as to the possible deficiencies in the mix and potential effects on properties such as workability, durability, and strength.

The linear equation to predict unit weight based on a given air content is presented below in directional form:

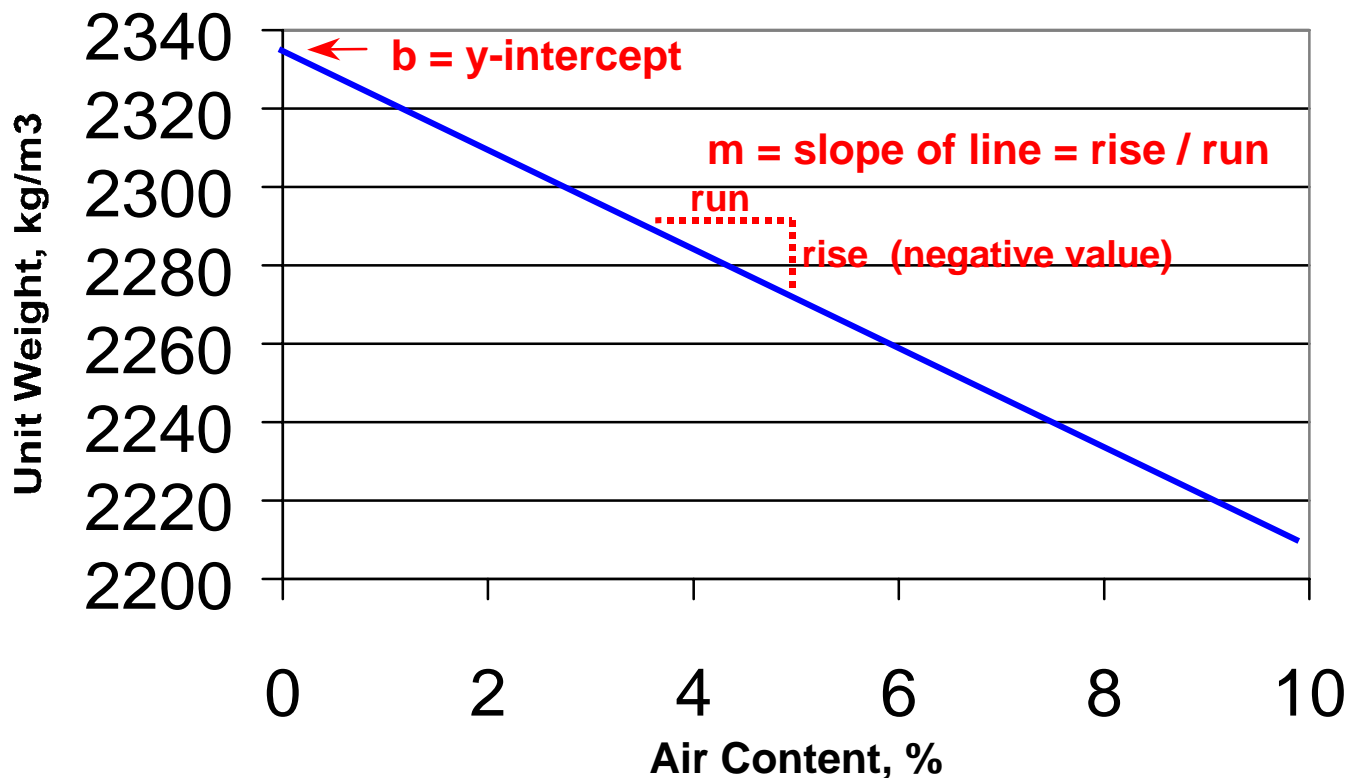
$$UW = m (\text{Air}) + b$$

Where: **m** is the slope of line (also known as "rise/run")

**Air** is the plastic concrete air content (independent variable, x-coordinate or abscissa of point)

**b** is the y-intercept

**UW** is the plastic concrete unit weight (dependent variable, y-coordinate, or ordinate of point)



**Figure 3.1**

If all points (Air, UW) associated with the solution set of this linear equation were plotted on a graph, there would be a straight line as illustrated by Figure 3.1. This linear relationship can be determined for any concrete mix design.

## Instructions for Page 2 of Mix Design & Proportioning Worksheets

If at least two points (Air, UW) are known to be a solution to the equation, algebra can be utilized to solve for the two unknown variables (i.e. slope and y-intercept). The form in Appendix D (tab 11) entitled "WORKSHEET FOR CMD LINEAR EQUATION" provides the format in which two points can be defined and the equation determined. The first major column of this worksheet with the heading "Mix Design 6.5% Target Air Content" is the starting point. These cells are simply filled with the numeric values previously determined from the proportioned mix design. The values shown in Table 3.5 are from the mix design and proportioning example presented earlier in this chapter.

Material	Mix Design 6.5% Target Air Content Yield = 1.000 m <sup>3</sup>		
	Weight Kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	<b>400.0</b>	3.150	<b>0.1270</b>
<b>Pozzolan</b>	-----	-----	-----
<b>Silica Fume</b>	-----	-----	-----
<b>FA</b>	<b>727.1</b>	<b>2.694</b>	<b>0.2699</b>
<b>CA</b>	<b>1033.4</b>	<b>2.739</b>	<b>0.3773</b>
<b>Water</b>	<b>160.8</b>	1.000	<b>0.1680</b>
<b>Air Content</b>	0.0	-NA-	0.0650
<b>Σ</b>	<b>2321.3</b>	-NA-	1.0000
<b>Unit Weight, ordinate for Point</b>	Pt. 2, $y_2 = 2321.3 \text{ kg/m}^3$		
<b>W / (C + P + SF), by weight</b>	<b>0.402</b>		
<b>100 FA / (FA+CA), % by volume</b>	<b>41.7</b>		

Table 3.5

The Cartesian coordinates (Air,UW) of one solution point is already available from the mix design. The plot of the coordinates ( $x_2 = 6.5$ ,  $y_2 = 2321.3$ ) is illustrated in Figure 3.2 and is designated Point 2.

Point 1, at coordinates ( $x_1$ ,  $y_1$ ), must now be determined. This is accomplished by removing air from the mixture and normalizing the batch weights of each ingredient to 1.0000 m<sup>3</sup>. Removal of air content from concrete will cause underyielding. A loss in air content from the target of 6.5% (yielding 1.0000 m<sup>3</sup>) to a value of 5.0% results in a 1.5% reduction in air content or 0.0150 m<sup>3</sup> reduction in yield (i.e.  $1.000 - 0.015 = 0.985 \text{ m}^3$ ).

To normalize the batch weights of ingredients when air content is reduced to 5.0 %, the design batch weights at 6.5% target air content must be divided by the yield at 5.0 % air content. These calculated values are

inserted in the Weight column under "Mix Proportions 5.0 % Air Content" as illustrated in Table 3.6 for the example problem.

Material	Mix Proportions 5.0% Air Content Yield = 0.985 m <sup>3</sup>		
	Weight kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	<b>406.1</b>	3.150	
<b>Pozzolan</b>	-----	-----	-----
<b>Silica Fume</b>	-----	-----	-----
<b>FA</b>	<b>738.2</b>	<b>2.694</b>	
<b>CA</b>	<b>1049.1</b>	<b>2.739</b>	
<b>Water</b>	<b>163.2</b>	1.000	
<b>Air Content</b>	0.0	-NA-	0.0500
<b>Σ</b>	<b>2356.6</b>	-NA-	

Table 3.6

The values for specific gravity remain unchanged and are inserted in the table. The absolute volume of each ingredient can now be determined by dividing the weight (kg) by the specific gravity, divided by the unit weight of water (1000 kg/m<sup>3</sup>). These values are illustrated in Table 3.7.

Material	Mix Proportions 5.0% Air Content Yield = 0.985 m <sup>3</sup>		
	Weight kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	406.1	3.150	<b>0.1289</b>
<b>Pozzolan</b>	-----	-----	-----
<b>Silica Fume</b>	-----	-----	-----
<b>FA</b>	738.2	<b>2.694</b>	<b>0.2740</b>
<b>CA</b>	1049.1	<b>2.739</b>	<b>0.3830</b>
<b>Water</b>	163.2	1.000	<b>0.1632</b>
<b>Air Content</b>	0.0	-NA-	0.0500
<b>Σ</b>	2356.6	-NA-	0.9991

Table 3.7

The summation of absolute volumes for the ingredients is sufficiently close to 1.0000 m<sup>3</sup>, therefore the unit weight at 5.0% air content can be calculated and recorded in the table as the ordinate of Point 1, as exemplified in Table 3.8.

Example:  $2356.6 \div 0.9991 = 2358.7 \text{ kg/m}^3$

<b>Unit Weight, ordinate for point</b>	Pt. 1, $y_1 = 2358.7 \text{ kg/m}^3$
<b>W / (C+P+SF), by weight</b>	<b>0.402</b>
<b>100 FA / (FA+CA), % by volume</b>	<b>41.7</b>

Table 3.8

A quick check of water/cementitious ratio (by weight) and percentage of fine to total aggregate (by volume) validates the numbers to be correct as these parameters remain unchanged from the mix design at 6.5% target air content. The weights of cementitious materials, fine aggregate, coarse aggregate, and water all increased per cubic meter of concrete as a result of underyielding.

The Cartesian coordinates of Point 1 ( $x_1 = 5.0$ ,  $y_1 = 2358.7$ ) is graphed along with Point 2 in Figure 3.3, to illustrate the example

From the x and y coordinates of Points 1 & 2, there is now enough information to determine the slope and y-intercept of the linear equation. The slope must be determined first. Since slope is otherwise known as "rise / run", the value in terms of the coordinates is as follows:

$$\text{Slope} = m = (y_2 - y_1) / (x_2 - x_1)$$

The slope for the example problem is:

$$\begin{aligned} \text{Example: } m &= (2321.3 - 2358.7) / (6.5 - 5.0) \\ m &= (-37.4) / (1.5) \\ m &= -24.9 \end{aligned}$$

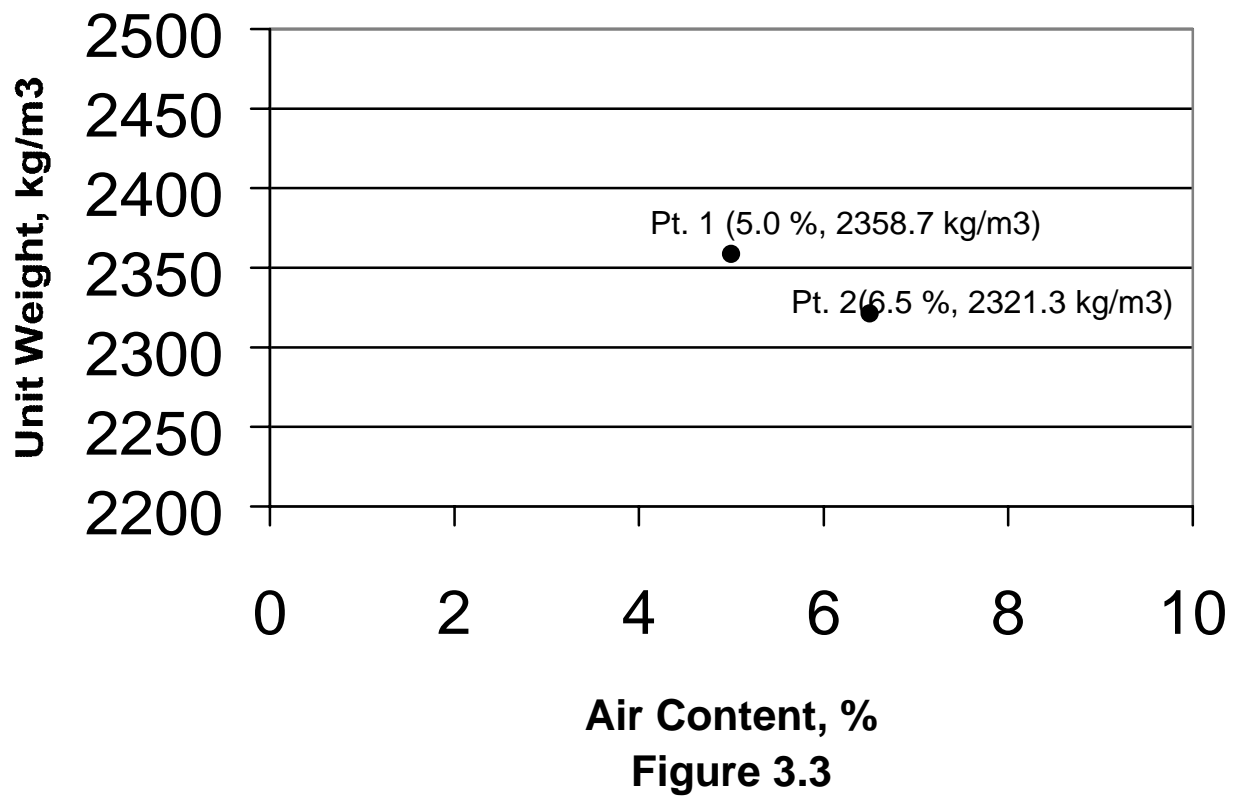
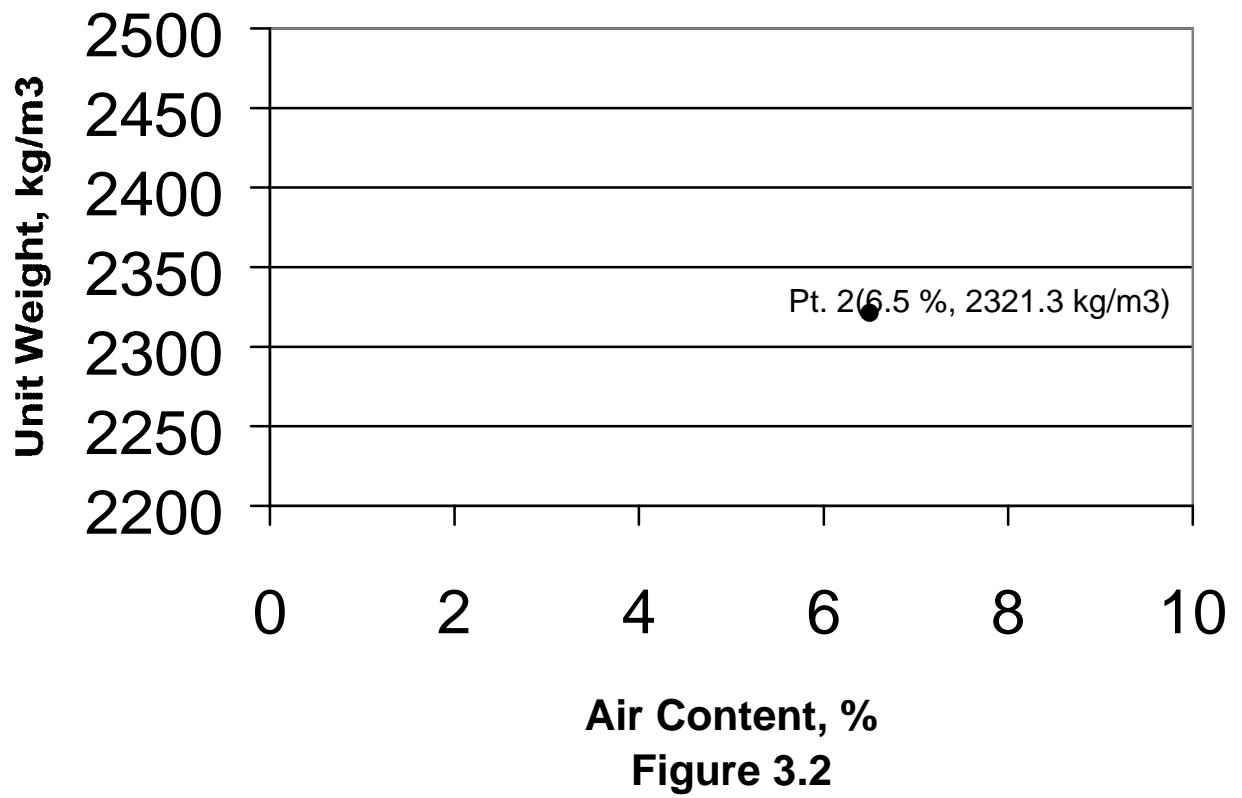
It is important to note that slope will always be negative since unit weight is inversely proportional to air content.

The y-intercept value can now be determined. The calculated slope and coordinate values for Point 2 can now be inserted into the linear equation to solve for the y-intercept (b). It should be noted that Point 2 is used in calculating the y-intercept in order to provide a uniform method and eliminate rounding error which may occur if Point 1 were used.

$$\begin{aligned} \text{Example: } UW &= m(\text{Air}) + b \\ \text{Use coordinate from Point 2 (6.5\%, 2321.3 kg/m}^3\text{)} \\ 2321.3 &= -24.9(6.5) + b \\ 2321.3 &= -161.8 + b \\ 2483.1 &= b \\ 2483 &= b \text{ rounded to the nearest whole kg/m}^3 \end{aligned}$$

The linear equation can now be written for the concrete mix design. The numbers from the example would result in the following:

$$\text{Example: } UW = -24.9(\text{Air}) + 2483$$



## THRESHOLD FOR MAXIMUM ALLOWABLE WATER / CEMENTITIOUS RATIO

Just as concrete unit weight is affected by changes in air content, it is also affected by the amount of water that is available to react with cementitious materials. As the amount of water increases the water/cementitious ratio also increases, producing concrete of inferior quality. This serves to lower the concrete unit weight at any given air content. Since the maximum allowable water/cementitious ratio for QC/QA superstructure concrete is 0.420, a threshold line or limit can be determined. This threshold line would be parallel to the linear equation for the mix design (i.e. same slope); however, the unit weight would be lower (i.e. lower y-intercept). The threshold limit has relevancy to results from quality control as well as Acceptance sampling and testing. Should the measured unit weight at any given air content be at or lower than the threshold, it could indicate that the maximum allowable water cementitious ratio was exceeded. It is important to understand that quality control works to center production about the linear equation for the mix design. Concrete production that has shifted toward the threshold line is considered very serious and requires corrective action to re-center it about the linear equation for the CMD.

The manner in which additional water could enter a concrete mix deserves consideration. Determination of the linear equation representing the threshold limit is not simply a matter of changing the water/cementitious ratio to 0.420 and reportioning. This would actually be another mix design and the difference would increase the risk of accepting deficient concrete. Likewise, to just increase the water content of the mix would result in a difference that increases the risk of rejecting acceptable concrete.

### Instructions for Page 3 of Mix Design & Proportioning Worksheets

The form for this worksheet is provided in Appendix D (tab 11). It provides a method to generate the threshold limit representing the maximum allowable water/cementitious ratio. The following instructions for completion of this worksheet are provided. The first step is to determine the total amount of cementitious materials targeted for the mix design. The total cementitious amount is multiplied by 0.420, which results in the maximum allowable water content. The example mix design within this chapter, is used to provide the following sample calculations:

$$\text{Example: } 400.0 \text{ kg/m}^3 \times 0.420 = 168.0 \text{ kg/m}^3$$

The maximum allowable water content is subtracted from the target water content established for the mix design. The difference is considered the amount of additional water that unintentionally enters a cubic meter of concrete.

$$\text{Example: } 168.0 \text{ kg/m}^3 - 160.8 \text{ kg/m}^3 = 7.2 \text{ kg/m}^3$$

The concrete mix design (CMD) batch weights are recorded in the second column of the worksheet for each corresponding material as illustrated in Table 3.9 for the example problem.

<b>Material</b>	<b>CMD Weights Kg/m<sup>3</sup></b>	<b>Water + / – kg/m<sup>3</sup></b>
<b>Cement</b>	<b>400.0</b>	-NA-
<b>Pozzolan</b>	-----	-NA-
<b>Silica Fume</b>	-----	-NA-
<b>FA</b>	<b>727.1</b>	-NA-
<b>CA</b>	<b>1033.4</b>	–
<b>Water</b>	<b>160.8</b>	+
<b>Air Content</b>	<b>0.0</b>	-NA-
<b>Σ</b>	<b>2321.3</b>	-NA-

Table 3.9

The amount of additional water is now recorded as a positive number in the third column in the row corresponding to the CMD water content. The amount of additional water is also recorded as a negative number in the row corresponding to the CMD coarse aggregate (CA) content. Coarse aggregate was selected because the majority of concrete production does not monitor moisture content variability of coarse aggregate. This methodology assumes the additional water is from the coarse aggregate only. Table 3.10 illustrates the numbers for the example problem.

<b>Material</b>	<b>CMD Weights Kg/m<sup>3</sup></b>	<b>Water + / – kg/m<sup>3</sup></b>
<b>Cement</b>	400.0	-NA-
<b>Pozzolan</b>	-----	-NA-
<b>Silica Fume</b>	-----	-NA-
<b>FA</b>	727.1	-NA-
<b>CA</b>	1033.4	<b>–7.2</b>
<b>Water</b>	160.8	<b>+7.2</b>
<b>Air Content</b>	0.0	-NA-
<b>Σ</b>	2321.3	-NA-

Table 3.10

The new batch weights (kg) are now entered under the major column heading entitled "Initial Batch Weights Prior to Normalizing". Weights for cementitious materials and fine aggregate are simply carried over and recorded in units of kg. The new values for coarse aggregate and water are determined by subtracting and adding the amount of additional water, respectively. The numbers for the example problem are entered in Table 3.11 to provide illustration.

Material	CMD Weights kg/m <sup>3</sup>	Water + / - kg/m <sup>3</sup>	Initial Batch Weights Prior To Normalizing		
			Weight Kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	400.0	-NA-	<b>400.0</b>	3.150	
<b>Pozzolan</b>	-----	-NA-	-----	-----	-----
<b>Silica Fume</b>	-----	-NA-	-----	-----	-----
<b>FA</b>	727.1	-NA-	<b>727.1</b>		
<b>CA</b>	1033.4	-7.2	<b>1026.2</b>		
<b>Water</b>	160.8	+7.2	<b>168.0</b>	1.000	
<b>Air Content</b>	0.0	-NA-	<b>0.0</b>	-NA-	0.0650
<b>Σ</b>	2321.3	-NA-	<b>2321.3</b>	-NA-	

Table 3.11

The specific gravities for each ingredient are entered in the table and used to calculate the corresponding absolute volumes. The resulting summation of absolute volumes must total  $1.0000 \pm 0.0005 \text{ m}^3$  in order for the proportioning to be correct (i.e. normalized). If the total volume is outside the tolerance, each weight of the ingredients must be divided by the yield and entered in the next major column entitled "1<sup>st</sup> Iteration to Normalize Weights." Table 3.12 illustrates the resulting calculations for the example problem.

Again the specific gravities for each ingredient are entered in the table and used to calculate the corresponding absolute volumes to complete the iteration. If the resulting summation of absolute volumes is within tolerance then the unit weight at 6.5% air content can be approximated to the required degree of accuracy. If the absolute volume summation were not within tolerance, a second and possibly a third iteration would be required to normalize the batch weights. Table 3.13 illustrates the resulting calculations for the example problem.

Material	Initial Batch Weights Prior To Normalizing			1 <sup>st</sup> Iteration To Normalize Batch Weights		
	Weight Kg	Specific Gravity	Volume m <sup>3</sup>	Weight kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	400.0	3.150	<b>0.1270</b>	<b>398.2</b>	3.150	
<b>Pozzolan</b>	-----	-----	-----	-----	-----	
<b>Silica Fume</b>	-----	-----	-----	-----	-----	
<b>FA</b>	727.1	<b>2.694</b>	<b>0.2699</b>	<b>723.8</b>		
<b>CA</b>	1026.2	<b>2.739</b>	<b>0.3747</b>	<b>1021.5</b>		
<b>Water</b>	168.0	1.000	<b>0.1680</b>	<b>167.2</b>	1.000	
<b>Air Content</b>	0.0	-NA-	<b>0.0650</b>	<b>0.0</b>	-NA-	
<b>Σ</b>	2321.3	-NA-	<b>1.0046</b>	<b>2310.7</b>	-NA-	

Table 3.12

Material	Initial Batch Weights Prior To Normalizing			1 <sup>st</sup> Iteration To Normalize Batch Weights		
	Weight Kg	Specific Gravity	Volume m <sup>3</sup>	Weight kg	Specific Gravity	Volume m <sup>3</sup>
<b>Cement</b>	400.0	3.150	0.1270	398.2	3.150	<b>0.1264</b>
<b>Pozzolan</b>	-----	-----	-----	-----	-----	-----
<b>Silica Fume</b>	-----	-----	-----	-----	-----	-----
<b>FA</b>	727.1	2.694	0.2699	723.8	<b>2.694</b>	<b>0.2687</b>
<b>CA</b>	1026.2	2.739	0.3747	1021.5	<b>2.739</b>	<b>0.3729</b>
<b>Water</b>	168.0	1.000	0.1680	167.2	1.000	<b>0.1672</b>
<b>Air Content</b>	0.0	-NA-	0.0650	0.0	-NA-	<b>0.0650</b>
<b>Σ</b>	2321.3	-NA-	1.0046	2310.7	-NA-	<b>1.0002</b>

Table 3.13

The summation of the Normalized Batch Weights divided by the summation of the corresponding absolute volumes, results in the Normalized Unit Weight from the iterations.

Example:  $2310.7 \text{ kg} \div 1.0002 \text{ m}^3 = 2310.2 \text{ kg/m}^3$

This value is subtracted from the Unit Weight for the CMD.

Example:  $2321.3 \text{ kg/m}^3 - 2310.2 \text{ kg/m}^3 = 11.1 \text{ kg/m}^3$

The difference is rounded to a whole kg/m<sup>3</sup> and subtracted from the y-intercept for the CMD linear equation to obtain the y-intercept for the threshold equation.

Example:  $11.1 \text{ kg/m}^3 = 11 \text{ kg/m}^3$  (rounded to whole value)  
 $2483 \text{ kg/m}^3 - 11 \text{ kg/m}^3 = 2472 \text{ kg/m}^3$

The slope of the threshold equation is the same value calculated for the mix design linear equation. There is now sufficient information to complete the equation on the worksheet.

Example:  $UW = -24.9 (\text{Air}) + 2472 \text{ kg/m}^3$

Figure 3.4 is a graphical representation of the example CMD linear equation and its corresponding threshold limit.

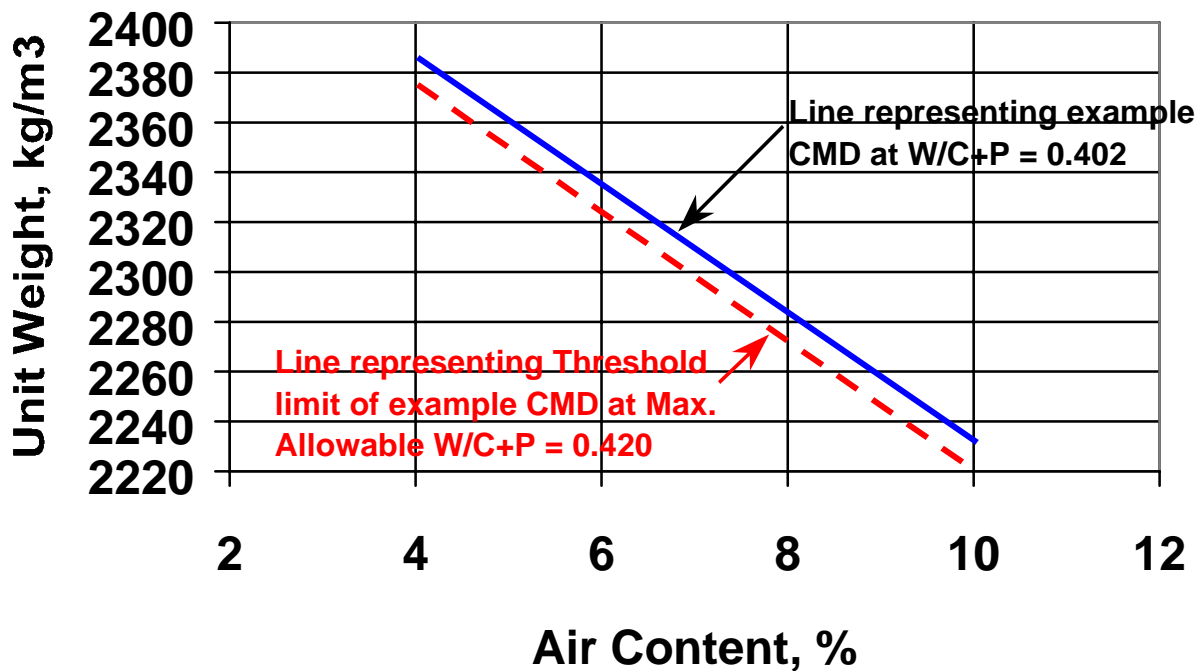


Figure 3.4

## DEPARTMENT CONCURRENCE OF MIX DESIGN

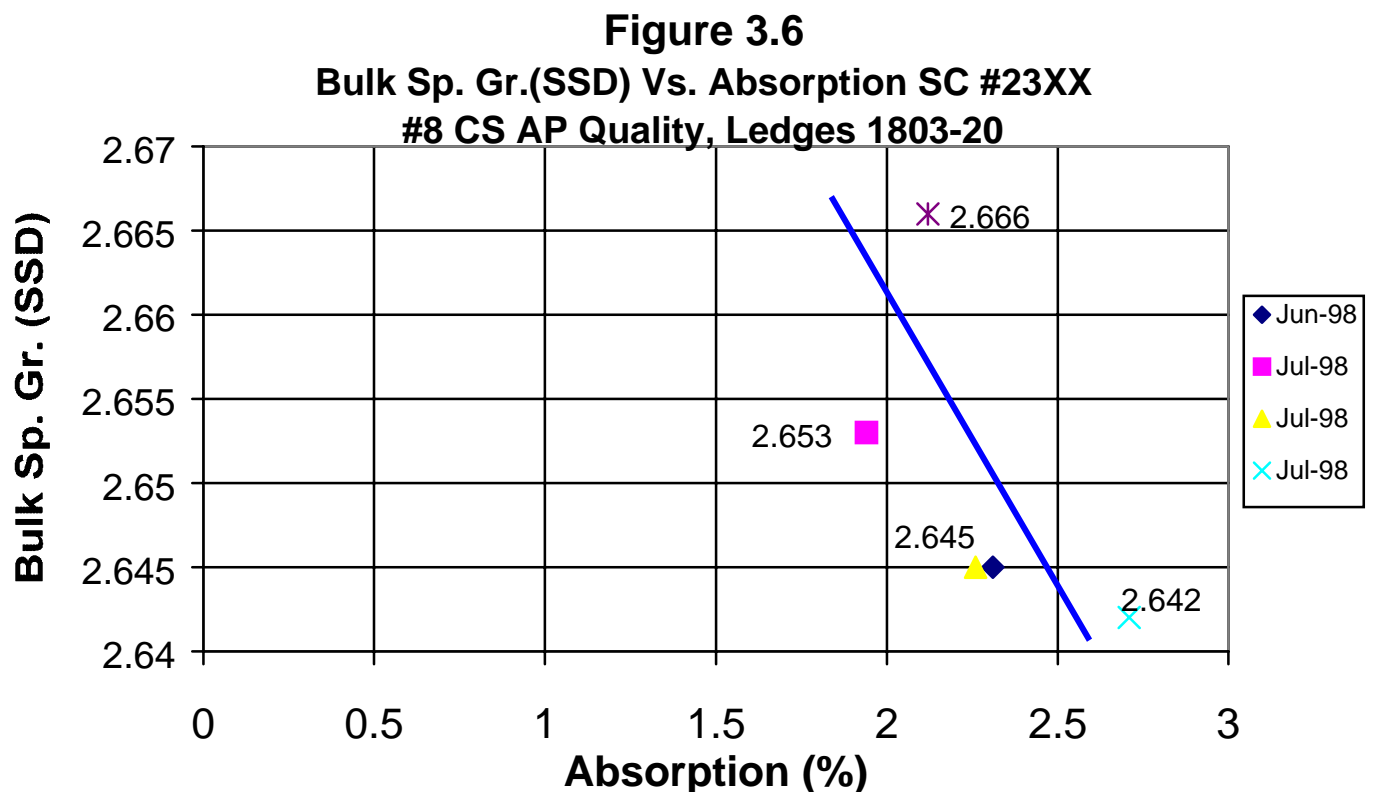
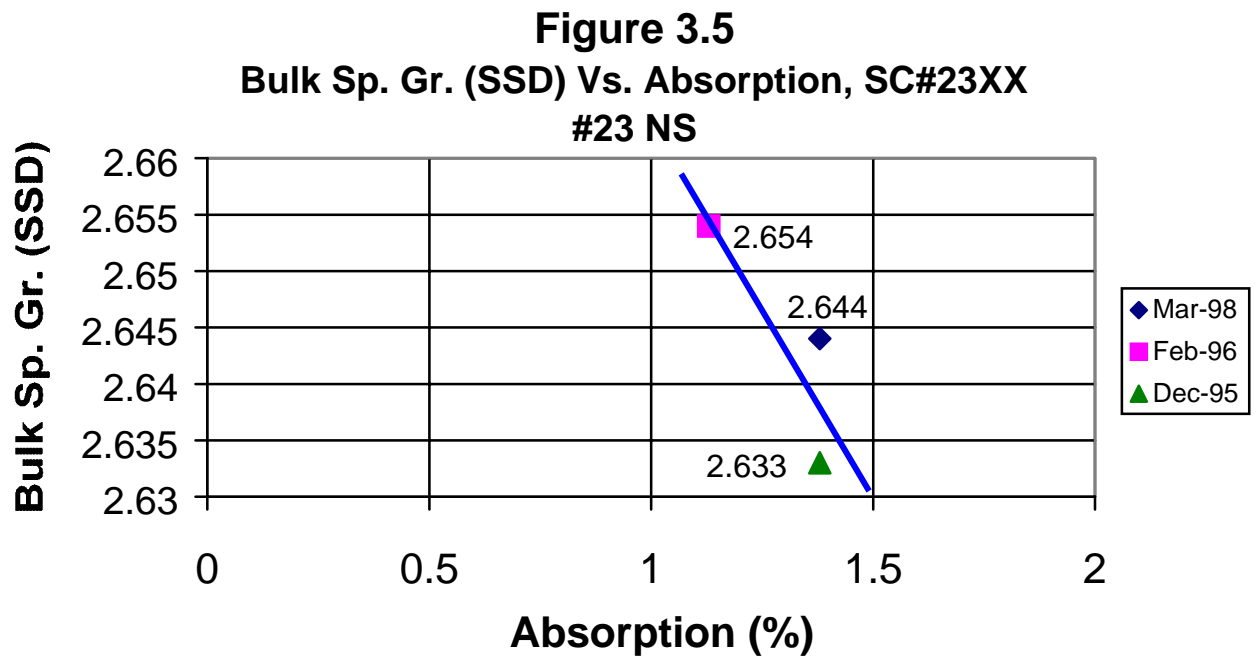
It is the responsibility of the Department's PE/PS to conduct a complete and thorough review of every mix design and proportioning for QC/QA Superstructure Concrete. There is a substantial amount of work that is based on the targets established by the CMD, not the least of which is the linear equation for the threshold limit that represents the maximum allowable water/cementitious ratio. This threshold limit is of critical importance in determining whether additional cylinders are to be cast as part of an acceptance sample for testing per AASHTO T 277 and subsequent action, which may involve a failed material investigation.

The first step in proper review of a CMD is to verify that the materials are from current approved sources. The list of Approved and/or Prequalified Materials, which are in effect for the contract, is to be used to acknowledge approved sources of cement, fly ash, GGBFS, and silica fume. The fine and coarse aggregate ingredient to the concrete mix must be material that INDOT acknowledges as coming from an approved Certified Aggregate Producer. The gradation and quality requirement for the aggregates must also be verified, particularly if stay-in-place deck forms are used to facilitate construction of the deck. If AP Quality coarse aggregate is required in the superstructure, it becomes imperative that the PE/PS substantiate the quality status. This would include the nature of the mining operations that produce aggregates of the desired quality (e.g. individual ledges or ledge combinations within the working bench of the aggregate source). If "Test 96" does not provide current information, the PE/PS must contact the District Materials & Tests Engineer or the District Geologist for confirmation.

The air entraining and chemical admixtures that are approved for use are as stated in the special provision and the Approved/Prequalified Materials Listing referenced therein. It is important to recognize the limitations of Type F admixtures or HRWR Admixture Systems. These chemical admixtures have no retarding capability and would not be appropriate for superstructure concrete that is placed in conditions where concrete and ambient temperatures are above 18°C (65°F), and where dead load deflections are of concern.

In addition to the aggregates gradations the PE/PS must verify the bulk specific gravity (ssd) and absorption for the fine and coarse aggregate as being reasonable for the source. If the contractor's value for absorption differs by more than 1.0% from the Department's value for the source the discrepancy shall be reported and subsequently investigated. The bulk specific gravity and absorption for aggregates are measured by the Department as part of the annual "Summary of Production Quality Results", and the periodic Point-of-Use samples. This data provides the correct basis for comparison of absorption and specific gravity. Figures 3.5 and 3.6 are graphs of bulk specific gravity (ssd) vs. absorption for a

fine and coarse aggregate and are presented as examples of what historical data might look like for specific products at an aggregate source.



Usually sources will demonstrate a trend of bulk specific gravity (ssd) being inversely proportional to absorption; however, such may not always be the case. Figure 3.6 represents data from INDOT Summary of Production Quality Results for a specific source of #8 coarse aggregate. The AP quality stone comes from ledges 1803, 1804, 19, & 20 processed as one working bench. These four ledges have thicknesses of 2.4 m, 2.7 m, 1.8 m, and 3.7 m, respectively. Since these ledges range in absorption from 2 % to 4 %, the consistency of bulk specific gravity and absorption depends on the aggregate source's ability to process the bench in a uniform manner. The District Geologist is the best source for obtaining historical data from "Summary of Production Quality Results" and "Point of Use" samples obtained from the aggregate source. They will assist the PE/PS in the proper review of contractor test results for aggregates.

If the contractor's test results for absorption and bulk specific gravity (ssd) are higher than expected, the test method could be the cause. It is important to remember that aggregates samples that begin the test for bulk (ssd) by soaking the material in the as receive condition, may result in higher bulk (ssd) and absorption than results from Department Point-of-Use or Production Quality results.

After verifying the materials as being approved for the concrete, the initial parameters for the Mix Design must be checked against the specification requirements. The remainder of the PE/PS check involves checking the math for proportioning, and the linear equations for the CMD and threshold limit. Use of the forms and worksheets by the contractor will provide the quickest and most complete review by the Department and therefore help eliminate unnecessary delays by recognizing problems early on.